



From pre-attentive processes to durable representation: An ERP index of visual distraction ☆, ☆ ☆



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ABSTRACT

Visual search and oddball paradigms were combined to investigate memory for to-be-ignored color changes in a group of 12 healthy participants. The onset of unexpected color change of an irrelevant stimulus evoked two reliable ERP effects: a component of the event-related potential (ERP), similar to the visual mismatch negativity response (vMMN), with a latency of 120–160 ms and a posterior distribution over the left hemisphere and Late Fronto-Central Negativity (LFCN) with a latency of 320–400 ms, apparent at fronto-central electrodes and some posterior sites. Color change of that irrelevant stimulus also slowed identification of a visual target, indicating distraction. The amplitude of this color-change vMMN, but not LFCN, indexed this distraction effect. That is, electrophysiological and behavioral measures were correlated. The interval between visual scenes approximated 1 s (611–1629 ms), indicating that the brain's sensory memory for the color of the preceding visual scenes must persist for at least 600 ms. Therefore, in the case of the neural code for color, durable memory representations are formed in an obligatory manner.

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1. Introduction

A lurid and influential theoretical claim has been made that vision has no memory in excess of 100 milliseconds: “Vision has no memory, it exists in the present tense” (Wolfe, 2000). Evidence for this claim about sensory memory has stemmed from demonstrations that a large change in a visual scene, or the sudden onset of a visual object, can go

unnoticed – phenomena, such as change blindness (O'Regan et al., 1999), inattentional blindness (Mack and Rock, 1998), and the attentional blink (Shapiro et al., 1997). Evidence from a flicker version of the change blindness paradigm (Rensink et al., 1997) suggests that sensory memory for the visual stimulation is thought to not even persist for 80 ms, unless stimulation receives some form of extensive attentional processing (Rensink, 2002). Accordingly, as in the inattention blindness and attentional blink paradigms, vision is shown to have no sensory memory.

On the other hand, the change detection process in vision is manifested as the visual mismatch negativity (vMMN) component of the event-related potential (ERP). This vMMN is typically elicited in a visual oddball paradigm when a repeated standard visual stimulus, such as a red square standard, is unpredictably and occasionally replaced by a deviant stimulus that differs from the standard stimulus by one feature, such as color, e.g., a green square deviant. Importantly, the inter-stimulus intervals between presentation of standard and deviant exceed 100 ms by far, suggesting that some representation of the standard persists. Such representation seems not to depend on attentional processing. The vMMN is also elicited when participants are ignoring the vMMN-eliciting features while attending to other aspects of the

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visual stimulation (Berti and Schröger, 2001, 2004, 2006; Kimura et al., 2008a,b).

The existence of vMMN, a scalp-elicited posterior bilateral negativity in response to visual deviance, has remained, until recently, a controversial topic (Näätänen, 1990, 1991; Cammann, 1990; Czigler, 1990; Pazo-Alvarez et al., 2003; Heslenfeld, 2003). However, throughout the past decade and into the current, a multitude of independent replications of the vMMN have placed vMMN upon a firm empirical footing (Astikainen and Hietanen, 2009; Astikainen et al., 2004, 2008; Berti, 2011; Clifford et al., 2010; Czigler, 2007; Czigler et al., 2004, 2007; Czigler and Pato, 2009; Czigler and Sulykos, 2010; Fisher et al., 2010; Flynn et al., 2009; Kimura et al., 2010a,c,d; Liu and Shi, 2008; Lyyra et al., 2012; Maekawa et al., 2009; Mao et al., 2004; Stefanics et al., 2011, 2012; Shtyrov et al., 2013; Sulykos and Czigler, 2011; Sušac et al., 2004, 2010a,b, 2011; for reviews, please see Kimura et al., 2011; Kimura, 2012; Winkler and Czigler, 2012). The vMMN is believed to be an analog of the more well-studied auditory MMN (Näätänen et al., 1978; Tiitinen et al., 1994), elicited at similar latencies and largely pre-attentively as well (Näätänen et al.; for a complementary perspective, see Erlbeck et al., 2015; Campbell, 2015). Yet functional differences could also exist between modalities — a key difference relating to the durability of the form of internal sensory memory representation indexed by vMMN. The orientation vMMN is elicited by an unexpected occasional change in orientation, occurring in response to visual stimuli separated by intervals of 200 ms, attenuating at intervals of 400 ms (Fu et al., 2003), and disappearing completely at intervals of 1100 milliseconds (Astikainen et al., 2008). Accordingly, the sensory memory responsible for the vMMN to orientation change is thought to only endure very brief intervals for vMMN. Thus the fleeting sensory memory for orientation in question is thought to have a duration of less than 1 s, as contrasts with estimates of 4–10 s for the pitch mismatch negativity in the auditory domain (Bottcher-Gandor and Ullsperger, 1992). However, the sensory memory for color may be considered more enduring: vMMN to color deviance can be elicited after intervals as long as 800 ms (Stefanics et al., 2011) albeit attenuated relative to a shorter interstimulus interval (ISI). The question of the duration of the to-be-ignored visual stimuli has remained open.

The value of an internal sensory memory representation for visual information has been subject to debate (Kimura et al., 2010b; O'Regan and Noë, 2001), the relatively static visual world typically being available as an external memory representation (Ballard et al., 1997). Indeed, the symbolic use of such external representations has been hailed as a major transition in human evolution (Donald, 1993), which compensates for the inherent limitations of working memory (see Miyake and Shah, 1999 for an overview).

Visual distraction paradigms have been shown to be promising in that they have revealed behavioral disruptions of performance produced by visual deviance, alongside a significant vMMN (Berti and Schröger, 2001, 2004, 2006; Kimura et al., 2008a,b). Further, it has been shown that when the to-be-ignored background exhibits deviance in the same dimension as the to-be-attended figure (color, orientation), the disruption of performance produced by the background is increased; alongside a concomitant vMMN augment (Czigler and Sulykos, 2010). However, vMMN to color change has not been shown to index distraction upon an individual level of performance (e.g., Czigler et al., 2002), whereas position deviance was effective in eliciting a vMMN as well as a behavioral distraction effect (Berti, 2009). To account for this difference, Berti (2009) suggested that peripheral presentation of color deviance might be necessary. In the present investigation, the amplitudes of significant differences between individual scalp-measured ERPs are thus evaluated as indices of behavioral distraction effects produced by to-be-ignored visual deviance, with the objective of assessing the functional relevance of vMMN to color change.

For this reason, a visual search task was adopted after Czigler et al. (2002); a paradigm which presented task-unrelated color deviance in the visual periphery, during which participants were required to look at a central fixation cross while searching for a unique target shape and ignoring a uniquely colored distractor within surrounding stimuli (Hickey et al., 2006). While the task of Czigler et al. (2002) did not prove sensitive to the distracting effects of color deviance, visual search distraction paradigms have been shown to be sensitive to color (Hickey et al., 2006). The present investigation aimed to evaluate the amplitudes of vMMN to color change of a distractor as indices of behavioral distraction, measured by the slowing of target processing. Crucially, the visual search task was extended by including a serial component: the distracting object differed in color from all other simultaneously presented objects, but that distractor occasionally changed in color within a sequence of trials. Hence, the effect of distraction was investigated in a series of visual search displays, where the distractor color was either a standard or a deviant color. Repetition of the uniquely colored “standard” distractor should facilitate the accumulation of a sensory memory trace for this color. To examine if the sensory memory mechanisms of the brain supported the detection of color change, an unexpected improbable “deviant” distractor (e.g., green) was employed. Note that this deviant differed in color from the preceding standard. Both the standard distractor and the deviant distractor differed in color from the remaining objects, which were blue. Visual Event-Related Potentials (ERPs) were derived from high-density EEG recordings to characterize the time-course of scalp-measured indications of the brain's responses to visual scenes containing deviant-colored distractors. A previously unexplored objective of the present investigation was thus to use these methods to build a new bridge between the discourses upon visual search and vMMN.

If as evidence from attentional blink, inattention blindness, and change blindness paradigms have suggested, vision has no memory (Wolfe, 2000) of functional consequence, upon an individual level, then color deviance would not affect behavior in our serial distraction task. To examine whether vision has a sensory memory for color, the interval between presentations of visual arrays of objects was at least 600 ms. That is, if a sensory memory for the color of the preceding distractor existed, that memory must endure that interval for a color change to influence: (a) performance, and (b) the generation of brain processes.

2. Method

2.1. Participants

Fourteen volunteers participated in this experiment in exchange for 4 cinema tickets. All participants gave their informed written consent voluntarily, with departmental ethical approval of the investigation, in accordance with the Declaration of Helsinki. Data from 2 participants had to be excluded from the analysis, because eye movements and blinking led to a loss of 65% of their data due to artifact rejection. The mean age of the remaining 12 participants (3 males) was 23.3 ± 2.5 years. All were right-handed and reported normal ($n = 4$) or corrected-to-normal ($n = 8$) vision.

2.2. Materials

Stimuli were presented on an LCD monitor (G2G 2 msec) at a 0% screen orientation with black as the background color. Each visual scene consisted of a stimulus array of 12 objects with a color frame (blue, green, or red), shaped either as a circle (3.43°) or a diamond (4.23°), with a horizontal or vertical line segment (1.38°) at the center. As illustrated in Fig. 1, the objects were placed circularly (radius of 9.3°) around a centrally presented fixation cross (1.38°). The luminance of the frame colors was adjusted to 35 cd/m^2 , using a luminance meter (Konica Minolta, LS-110, with closing-up lens, correction factor

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